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RESEARCH MEMORANDUM

NOTE ON HOVERING TURNS WITH TANDEM HELICOPTERS

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SUMMARY

The source of an appreciable pitching-moment difference between left and right hovering turns for a tandem helicopter is described. The difference in pitching moment results from the difference in rotational speed of the counterrotating rotors with respect to the air while the helicopter is turning.

INTRODUCTION

There have been accidents with tandem helicopters, one very recently, involving hovering turns over a spot. In these accidents the helicopter had nosed down to such a steep attitude during the turn that recovery before contact with the ground was not accomplished. Aerodynamic phenomena were thought by some to have been the primary cause of the loss of control. Consequently, a brief evaluation flight without recording instrumentation was made with a tandem helicopter to study its behavior in such maneuvers.

HELICOPTER AND TESTS

The helicopter used had overlapped, staggered rotors of 35-foot diameter with 21 feet 11 inches between centers. The direction of rotation of the forward rotor is clockwise when viewed from above, and that of the rear rotor counterclockwise. The weight of the helicopter was about 5,600 pounds and the center of gravity was at station 179, about 1 inch behind the point midway between the rotors. The helicopter had a horizontal tail surface with large canted fins at the tips. The helicopter is shown in figure 1.

The site of the investigation was flat with no obstructions for a considerable distance. At the time of the tests, a fairly steady wind averaging 10 mph was blowing. The helicopter was rotated in these tests

with the pilot's position approximately fixed with respect to the ground. Also, the turns were made with as nearly fixed pedal displacements as possible and thus approximately constant angular velocity was produced. This helicopter is normally equipped with a small quadrant and pointer on the floor to indicate stick position with respect to desirable trim positions for hovering and 80 knots forward speed. The control deflections needed in the present test maneuvers were noted on this quadrant by the observer.

RESULTS

It was first determined that the power necessary to hover was approximately the same at all headings with respect to the wind. Thus, the wind in this case did not appear to have appreciable effect on interference with respect to power required.

The static downwash effects were evaluated by noting the cyclic control position while hovering steadily with nose into the wind as compared with hovering with tail into the wind. With tail into the wind, these effects were found to require a stick position about 2 inches aft of that when headed into the wind.

Next, turns over a spot were made to left and right at several rates. When starting from a position with nose into the wind, turns to the left at only moderate rates produced appreciable nose-down pitching. There was a nose-down attitude change although enough control was used to prevent translational velocity of the pilot with respect to the ground. The maximum pitch-attitude change appeared to occur at about the 180° position. The control deflection required to counteract the pitching for a rate of turn of 360° in an estimated 7 to 10 seconds, which was felt to be a maximum for reasonable safety, was about 4 inches. This deflection was twice that required for static hovering with the tail into the wind.

In contrast to the left turns, comparable turns to the right produced no appreciable pitching or attitude change as far as the pilot was concerned although the maximum aft stick deflection required approximated that for static hovering with the tail into the wind.

When a turn to the left was begun from a position with tail into the wind, the nose-down pitching tendency did not become apparent until the last 90° of the 360° turn. This is the portion of the turn during which the effects of the rear rotor advancing into the wind would be evident. Performing this maneuver to the right again produced no appreciable pitching.

ANALYSIS

The translational velocity of the rear rotor produced by the turns could be expected to have some effect inasmuch as the power required for steady, level flight is reduced as forward speed is increased at very low speeds (approximately 10 to 25 knots). The effect of the wind must also be taken into account. On the day of this particular test, the wind velocity averaged 10 mph or about 15 fps. The velocity of the rear rotor produced by a turn of 360° in 7 seconds, or 0.9 radian/second, is about 20 fps. Thus there could be expected a maximum nose-down pitching moment caused by the difference in inflow through the front rotor in steady flight at 15 fps as compared with the rear rotor at 35 fps. This moment would be in the nose-down direction, however, for either left or right turns. Obviously, therefore, this effect and the effect of the downwash change do not account for the differences between left and right turns.

It was suggested that there is a difference in rotor rotational speed with respect to the undisturbed air between front and rear rotors during these turns. The rotor rotational speed is about 30 radians/second for this helicopter. Assuming a rate of turn of 0.9 radian/second the ratio of rotor thrusts in the turn would be $(30.9/29.1)^2$ or 1.13. This represents about a 170-pound change in thrust at each rotor, or about 3,700 foot-pounds of pitching moment. Since the pitching moment of inertia for this helicopter is about 10,000 slug-feet^2, this pitching moment would produce about 1/3 radian/second^2 pitching angular acceleration if unchecked. Thus, the origin of an appreciable pitching moment is indicated.

The direction of this moment reverses if the direction of turn is reversed. For this helicopter, the moment would be nose down in a left turn and nose up in a right turn. Therefore, the nose-down pitching moments produced by translational velocity of the rear rotor would add to those produced by the effective change in rotational speed of the rotors for a left turn, and would tend to cancel in right turns. The reversal of the interference effects when going from nose into wind to tail into wind may cause a large change in trim position of the cyclic stick; however, this change would be independent of the direction or rate of the turning. The calculations indicated that for a 0.9 radian/second turn the cyclic stick displacement required to correct for the effective rotational-speed difference between the rotors would be about 0.75 inch. At the 180° position of the turn, the effect of translational velocity and a 15-fps wind would also require about 0.75-inch aft stick displacement. Consequently, in a left turn the stick displacements required by these two effects would add to become 1.50 inches, whereas in a right turn they would cancel entirely. It must be pointed out, however, that the effects of translational velocity

at the rear rotor, considering wind, is a maximum when the rear rotor is advancing into the wind (fuselage broadside to the wind). The calculated stick displacement to offset this maximum effect of translational velocity for the case considered is about 1.66 inches.

The results of this rough analysis would appear to confirm, at least qualitatively, the flight observations of a difference in longitudinal control required for trim between turning right or turning left over a spot with a tandem helicopter.

CONCLUDING REMARKS

The source for an appreciable pitching-moment difference between left and right hovering turns for a tandem helicopter is described. The difference results from the difference in rotational speed of the rotors with respect to the air while the helicopter is turning. This moment is independent of wind but its sign depends on the direction of turn. The effects of the difference in translational velocity of the rear rotor with respect to the front rotor add to the effects due to turning in the critical direction, in this case a left turn.

It is considered desirable that pilots be acquainted with this phenomenon so that difficulties may be avoided. Rapid turns should be made in the noncritical direction, or should be approached with caution.

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Figure 1.- Test helicopter.